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& JP010251727

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(54) Bonding wire for semiconductor devices

(57) A bonding wire for semiconductor devices is manufactured by a process which includes applying a lubricant to a wire and taking measures to ensure good adhesion between the lubricant and the wire. In particular wire may be cooled to directly after final annealing at a rate of 1000°C/sec. or more. Alternatively, the wire may be withdrawn form the lubricant solution at an angle of between 50 and 60° to the surface of the solution. In a yet further alternative the wire is given a surface removal treatment after annealing.

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FIG. 1

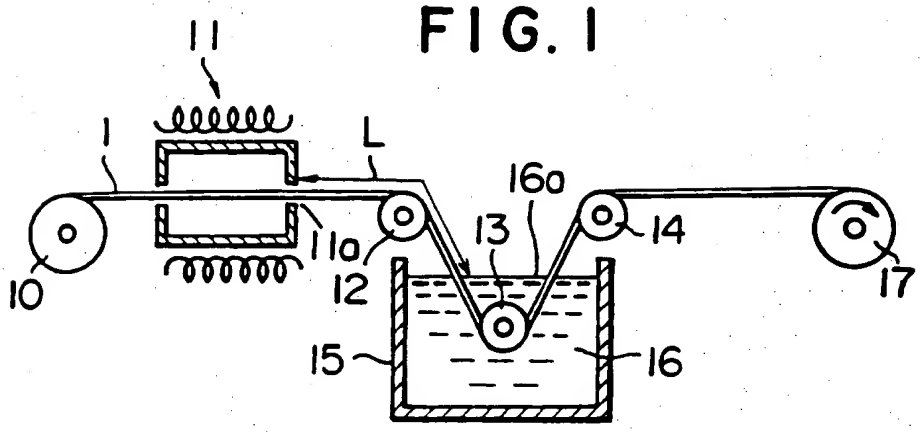


FIG. 2

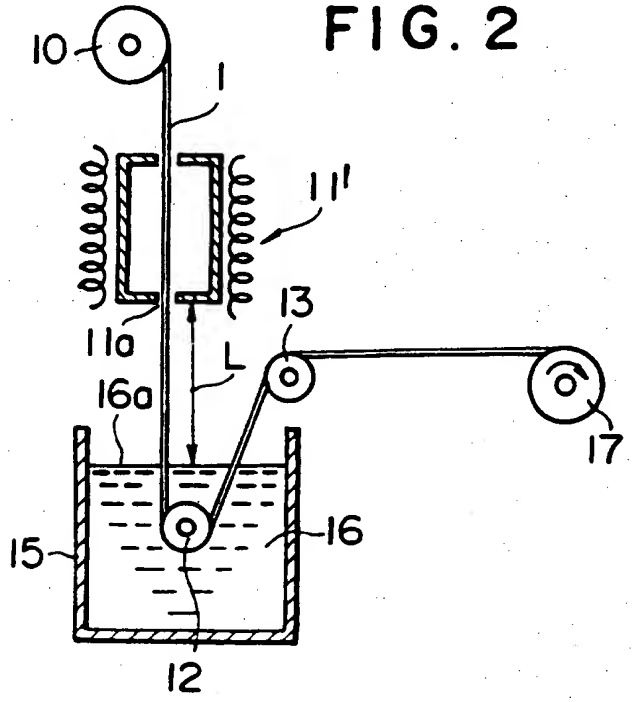


FIG. 3

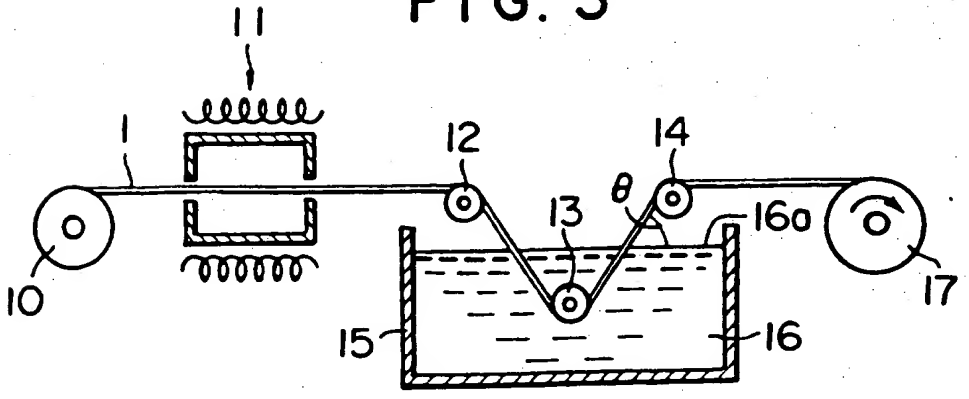


FIG. 4

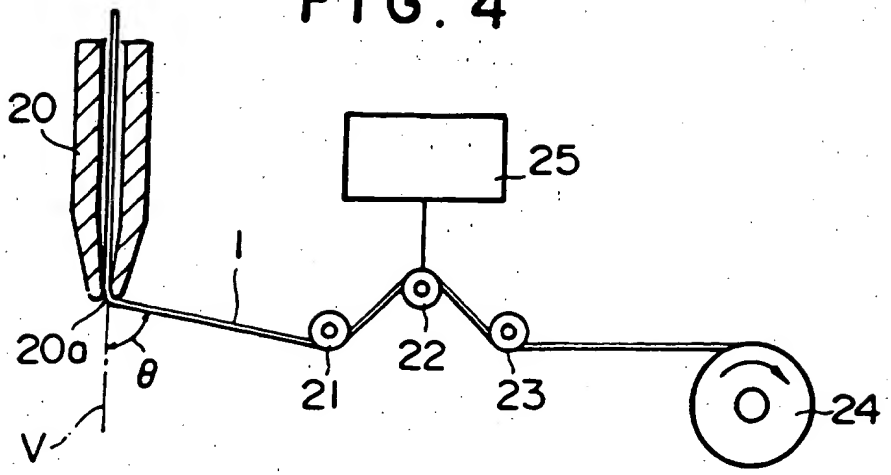


FIG. 5A

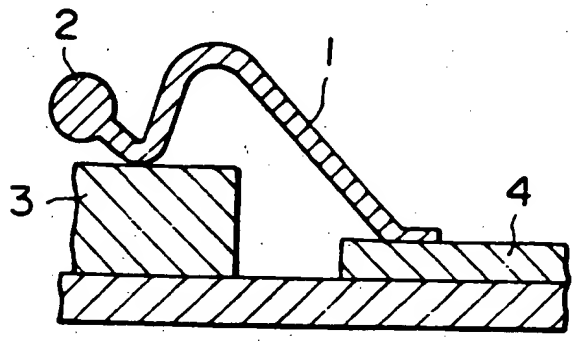
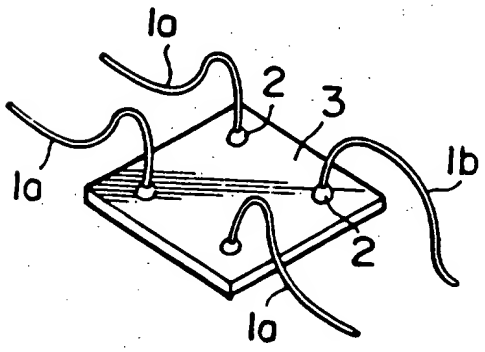


FIG. 5B



METHOD OF MANUFACTURING BONDING WIRE FOR SEMICONDUCTOR DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method of manufacturing a semiconductor device bonding wire used for assembly of a semiconductor device, and particularly to a method of manufacturing a bonding wire capable of reducing exchange frequency of a capillary of a bonding machine even in the case where IC chip electrodes are bonded with external leads under such a severe condition as forming a loop by reverse deformation.

2. Description of the Related Art

As is well known, for bonding IC chips to external leads upon assembly of a semiconductor device mounting the IC chips, there has been used a bonding wire made of a metal element selected from a group consisting of Au, Pd, Al, and Cu or an alloy mainly containing one kind selected from a group consisting of Au, Pd, Al, and Cu.

Conventionally, the bonding wire has been manufactured by a method wherein an ingot of a metal element or an alloy having a specified composition is prepared by melting and casting; the ingot is subjected

to plastic working such as rolling or extrusion and is repeatedly subjected to drawing and intermediate annealing, to form an intermediate wire; the intermediate wire is finally drawn, to form an ultra-fine wire having a diameter of about 10-50 μm; the ultra-fine wire is cleaned, finally annealed, and cooled; and the resultant wire is subjected to a post-treatment, for example, it is coated with wire lubricant.

The bonding wire thus obtained is wound around a spool by a specified length and is attached to a bonding machine, and is used for wire bonding working.

Incidentally, there has been a strong requirement in the recent semiconductor devices toward the increased number of pins, and to meet such a requirement, in the wire bonding method, wiring must be performed between such a lot of pins and the corresponding external leads, with a result that bonding wires are required to be deformed to form long loops for ensuring a specified pitch between the external leads.

The formation of a long loop of a bonding wire, however, tends to cause abnormality in stability of the loop shape, and consequently the bonding wire is easier to be hung in the vertical direction and tilted in the

longitudinal direction, thereby leading to a risk of short-circuit.

To cope with this problem, an attempt has been made to stabilize the loop shape by performing the so-called reverse deformation, wherein in the process of forming a loop using a bonding machine, a bonding wire is bent in the direction reversed to the loop forming direction and then deformed to form a normal loop.

However, upon the continued loop formation of the bonding wire obtained by the above-described prior art manufacturing method using the reverse deformation method, there occurs a variation in the wire length per one bonding portion, thereby causing an abnormal loop. The abnormal loops or irregular loops shown in Figs. 5(a) and (b) are hereinafter simply referred to "abnormal loop". The typical abnormal loops include the so-called neck bonding abnormal loop shown in Fig. 5(a) wherein a neck portion positioned before a ball 2 formed at the leading end of a wire 1 is bonded with the upper surface of an IC chip 3; and an abnormal loop 1b shown in Fig. 5(b) which is drawn longer than a normal loop 1a by a specified length.

The generation of a variation in the wire length per one bonding portion is due to a deterioration of a

capillary of a bonding machine caused by the reverse deformation. This brings a problem in that an expensive capillary must be frequently exchanged.

SUMMARY OF INVENTION

In view of the foregoing, the present invention has been made, and an object of the present invention is to provide a method of manufacturing a bonding wire capable of increasing the bonding number until an abnormal loop due to a variation of the wire length per one bonding portion is generated, even in the case where a loop of a bonding wire is formed by a bonding machine in a severe mode of the so-called reverse deformation in which the bonding wire is bent in the direction reversed to the loop forming direction before the formation of a normal loop, thereby significantly reducing the exchange frequency of an expensive capillary of the bonding machine.

The present inventors have earnestly examined to achieve the subject of the present invention (hereinafter, referred to as "present subject"), and found the fact that it is effective to increase the adhesiveness between a wire and lubricant present on the wire surface and to prevent the sticking of foreign

matters on a capillary of a bonding machine. On the basis of this knowledge, the present invention has been accomplished.

A method of manufacturing a bonding wire according to the present invention is different from other manufacturing methods pertaining to the related technical field in terms of provision of a means of increasing the adhesiveness of wire lubricant against a wire.

Specifically, when the bonding is performed using a wire cleaned in its surface to remove foreign matters and coated with no wire lubricant in the final process of manufacturing a bonding wire, the bonding number until generation of an abnormal loop, which is the present subject, is lowered, thereby increasing the exchange frequency of a capillary. The reason for this is considered as follows: namely, when the wire passes through a bonding machine, it grinds members of the bonding machine because of the poor sliding property, and the foreign matters thus ground are stuck on a capillary and act to increase the friction between the wire and the capillary, with a result that an abnormal loop is generated due to the increased friction, thereby

reducing the bonding number until generation of the abnormal loop.

Accordingly, to reduce the friction between a wire and members of a bonding machine, the coating of wire lubricant on the surface of the wire is considered to be effective.

However, when bonding is performed using a wire obtained by the prior art manufacturing method in which the wire surface is coated with wire lubricant in the final process but the adhesiveness of wire lubricant against a wire is not examined, the bonding number until generation of an abnormal loop, which is the present subject, is increased somewhat but it is practically insufficient.

As described above, the present inventors have found the fact that the bonding number until generation of an abnormal loop can be significantly increased even in the case where the loop formation of a bonding wire is performed in a severe mode of reversed deformation by increasing the adhesiveness of wire lubricant against the wire, and have accomplished the present invention on the basis of this knowledge.

The methods of increasing the adhesiveness of wire lubricant against a wire include the following three means.

As described in claim 1, the first means comprises the step of cooling a wire after final annealing at a cooling rate of 1000°C/sec or more (described later).

As described in claim 5, the second means comprises the steps of drawing a wire using water-soluble lubricant for cold-working, and coating the wire with wire lubricant by dipping the rewound wire in wire lubricant solution and taking out the wire from the solution at an angle between the wire taking-out direction and the wire lubricant solution surface which is specified at 50-60°.

As described in claim 7, the third means comprises the step of applying a surface layer removing treatment to an intermediate wire.

The manufacturing method of the present invention includes at least one of these means, and therefore, it can increase the adhesiveness of wire lubricant against a wire.

Accordingly, in the case where the bonding wire obtained by the manufacturing method of the present invention is subjected to bonding work by a bonding

machine, an abnormal loop is difficult to be generated even when the bonding is performed in a severe condition that the loop is formed by reverse deformation, thereby reducing the exchange frequency of an expensive capillary of the bonding machine.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic view showing one example of a cooling process after final annealing according to a manufacturing method of the present invention;

Fig. 2 is a schematic view showing another example of the cooling process after final annealing according to the manufacturing method of the present invention;

Fig. 3 is a schematic view showing one example of a wire lubricant coating process according to the manufacturing method of the present invention;

Fig. 4 is a schematic view showing the outline of a wire sliding resistance test used in the present invention; and

Figs. 5(a) and 5(b) are schematic views showing examples of abnormal loops of a bonding wire prepared by a prior art manufacturing method, which are generated upon forming loops by reverse deformation in bonding work using a bonding machine.

DETAILED DESCRIPTION OF THE INVENTION

The outline of preferred processes of manufacturing a bonding wire according to the present invention will be described. An ingot of a metal element or an alloy having a specified composition is prepared by melting and casting. The ingot is subjected to plastic working (rolling or extrusion), and is repeatedly subjected to drawing and intermediate annealing, to prepare an intermediate wire. The intermediate wire is finally drawn, to prepare a ultra-fine wire, and the ultra-fine wire is subjected to post-treatment. As the post-treatment, the ultra-fine wire is cleaned and finally annealed, and after cooling (or during cooling), it is coated with wire lubricant. The outline of the manufacturing processes is the same as that of the prior art, and the feature of the present invention lies in that a process of increasing the adhesiveness of wire lubricant is added in the above-described processes.

The method of increasing the adhesiveness of wire lubricant includes the following three means.

The first means comprises the step of cooling a wire directly after final annealing using cooling water

at a cooling rate of 1000°C/sec or more, specifically, defined by the following equation.

cooling rate (°C/sec)

= (wire speed) × [(atmospheric temperature in annealing furnace - cooling water temperature)/(distance between outlet of annealing furnace and cooling water surface)]

The second means comprises the steps of drawing a wire using water-soluble lubricant for cold working, and coating the wire with wire lubricant by dipping the rewound wire in wire lubricant solution and taking out the wire from the solution at an angle between the taking-out direction and the wire lubricant solution surface which is specified at 50-60°

The third means comprises the step of applying surface layer removing treatment to an intermediate wire.

The present invention includes at least one of the above-described means.

Additionally, in the present invention, an ultra-fine wire obtained by final drawing is usually wound around a spool using a winder, and the wire is subjected to post-treatment such as cleaning, final annealing,

cooling and coating of wire lubricant while being rewound using a rewinder.

The bonding wire of the present invention is made of a metal element selected from a group consisting of Au, Pd, Al, and Cu or an alloy mainly containing one kind selected from a group consisting of Au, Pd, Al, and Cu incorporated with specified other additional elements. Of these metal elements, an Au alloy is preferable because of high corrosion resistance and high reliability. The bonding wire is used in the form being finally drawn in a ultra fine wire having a diameter of about 10-50 μm.

In the present invention, the bonding wire is adjusted by final annealing such that the elongation percentage becomes 2-10%.

Hereinafter, the present invention will be more fully described.

[First Means]

A manufacturing method, in which the adhesiveness of wire lubricant is obtained by the first means as described in claims 1 to 4, will be described. Specifically, the first means comprises the step of cooling a wire directly after final annealing using

cooling water at a cooling rate of 1000°C or more, specifically, defined by the following equation.

cooling rate (°C/sec)

= (wire speed) × [(atmospheric temperature in annealing furnace - cooling water temperature)/(distance between outlet of annealing furnace and cooling water surface)]

According to this manufacturing method, an ingot of a metal or an alloy having a specified composition prepared by melting and casting is subjected to plastic working such as rolling or extrusion, and then to drawing and intermediate annealing, to prepare an intermediate wire; the intermediate wire is finally drawn, to prepare a wire having a specified diameter; the fine wire is cleaned and finally annealed, and directly cooled with cooling water at a cooling rate of 1000°C/sec or more, preferably, 1000-30000°C/sec; and after (or during cooling), the resultant wire is coated with wire lubricant.

In this manufacturing method, the furnace atmospheric temperature in the final annealing is specified to be in the range of 300 to 650°C in accordance with the kind of an alloy. The annealing is performed by passing the wire through the annealing

furnace at a specified speed. To obtain the above-described specified elongation percentage, the wire speed passing through the annealing furnace is preferably in the range of from 30 to 60 m/min.

Hereinafter, the cooling process performed directly after the final annealing, which is one of the features of the present invention, will be described.

First, in the case where the final annealing is performed using a horizontal annealing furnace 11 shown in Fig. 1, a wire 1 finally drawn and cleaned by a specified method is rewound from a rewinder 10 and is annealed in the annealing furnace 11; the wire 1 is introduced in a cooling water bath 15 by way of a first roller 12, and is cooled with cooling water 16; and the wire 1 is wound using a winder 17 by way of a second roller 13 and a third roller 14.

In this cooling process, the cooling rate defined by the above-described equation is required to be more than 1000°C/sec.

By cooling a wire at a cooling rate more than 1000°C/sec, the bonding number until generation of an abnormal loop, which is the present subject, is increased even upon formation of a loop by reverse deformation.

The cooling rate is preferably in the range of more than 2000°C/sec.

To achieve the above-described cooling rate, a distance L between an outlet 11a of the annealing furnace and a cooling water surface 16a (wire feeding distance from the outlet 11a of the annealing furnace to the cooling water surface 16a) is preferably shortened.

Specifically, to obtain a cooling rate of 1000°C/sec or more in the condition that a temperature difference between the atmospheric temperature in the annealing furnace and the cooling water temperature is 600°C and the wire speed is 60 m/min, the above-described distance L is required to be 60 cm or less.

In the case of the temperature difference of 300°C, the distance L is required to be 30 cm or less.

To increase the cooling rate, the distance L is required to be further shortened.

A vertical annealing furnace 11' shown in Fig. 2 is more preferable than the horizontal annealing furnace 11 shown in Fig. 1 to shorten the distance L. This is because, in the vertical annealing furnace 11', the cooling water bath 15 can be relatively freely disposed.

In the prior art, the distance L between the outlet 11a of the annealing furnace and the cooling water surface 16a has been set at 1 m or more.

The reason for this is that, in the prior art, water cooling has been performed after sufficient air cooling.

In the case of the distance L of 1 m, when the temperature difference between the atmospheric temperature in the annealing furnace and the cooling water temperature is 400°C and the wire speed is 60 m/min, the cooling rate becomes 400°C/sec. Even in the case where the above-described temperature difference is 600°C, the cooling rate is 600°C/sec.

For the cooling rate being less than 1000°C/sec, even in the case where the wire is coated with wire lubricant after or during cooling, there occurs a disadvantage that the bonding number until generation of an abnormal loop, which is the present subject, is small when the loop formation is performed by reverse deformation.

For this reason, the cooling rate is specified at 1000°C or more.

In addition, when the atmospheric temperature in the annealing furnace is in the range of from 300 to

600°C and the wire speed is in the range of 30 to 60 m/min, the cooling rate can be increased up to about 50000°C/sec by making small the distance L between the annealing furnace and the cooling water surface. However, in terms of the equipment, it is undesirable to make small the distance L to a value less than 1 cm. Accordingly, the preferable upper limit of the cooling rate is 3000°C/sec.

As the wire lubricant used in this manufacturing method, a fat and oil series lubricant capable of coating the surface of a wire with organic carbon.

The specific examples of the fat and oil series wire lubricants include a mineral oil system such as paraffin series hydrocarbon, naphthene series hydrocarbon, and aromatic hydrocarbon; a synthetic oil system such as polyolefin, alkylbenzene, fatty acid, higher alcohol, fatty acid soap, polyglycol, polyphenylether, fatty acid diester, polyol ester, polyoxyethylene alkylether, sulfonate, amine, amine salt, silicone, phosphoric ester, fluorocarbon, fluoropolyether, fluoroglycol; and animal/plant oil system such as beef tallow, lard, palm oil, soya bean oil, rape bean oil, castor oil, and rosin oil.

Of these materials, the fatty acid series synthetic oil is preferably used for increasing the adhesiveness against a wire.

The wire is coated with the above-described wire lubricant by dipping the wire in a solution of the wire lubricant diluted with water. The film thickness of the lubricant is preferably in the range of 1 to 30 Å (10^{-10} cm). The film thickness is controlled by adjusting the concentration of the wire lubricant diluted with water. The wire lubricant is preferably diluted with water in the concentration of 5-300 weight ppm.

The solution of the wire lubricant diluted with water may be used as cooling water in the cooling process. In this case, directly after final annealing, the coating of the wire lubricant can be performed together with the cooling at a cooling rate of 1000°C/sec or more. This can achieve the excellent effect to the present subject and also shorten the processes.

The reason why the processes of finally annealing the drawn wire at a furnace atmospheric temperature ranging from 300 to 650°C; directly cooling the wire at a cooling rate of 1000°C/sec or more; and after or during cooling, coating the wire with wire lubricant are

significantly effective for the present subject, is not apparent; however, it seems that the above-described processes make fine the crystal structure of the wire thereby increasing the adhesiveness between the wire and the coating agent (wire lubricant) present on the surface of the wire.

Namely, in the case the adhesiveness between the wire and the wire lubricant is high, even when the loop formation is performed by a severe mode of reverse deformation, the wire lubricant is difficult to be separated from the wire, that is, the lubricant is difficult to be stuck on a capillary, thereby reducing the resistance between the wire and the capillary. This prevents the generation of an abnormal loop, which is the present subject, to thus reduce the exchange frequency of the capillary.

The first means will be more clearly understood with reference to the following inventive examples and comparative examples shown in Tables 1 and 3.

(Inventive Example 1)

An ingot (diameter: 30 mm) of a Au alloy containing Y in an amount of 40 weight ppm was rolled between grooved rolls, being repeatedly subjected to drawing and intermediate annealing, and was finally drawn into a

wire having a diameter of 25 μm. The wire was finally annealed using a vertical annealing furnace shown in Fig. 2 while being rewound from a rewinder 10, and directly it was cooled using wire lubricant solution as cooling water 16 and then rewound using a rewinder 17. At this time, the annealing furnace temperature (atmospheric temperature in the annealing furnace) was set at 420°C; the wire speed was 60 m/min; the distance L between an outlet 11a of the annealing furnace and a cooling water surface 16a was 40 cm; and the cooling water temperature (temperature of the wire lubricant solution) was 20°C. Also, the wire was annealed by adjusting the length of the heating zone in the annealing furnace such that the elongation percentage become 4%. The cooling rate was 1000°C/sec. As the cooling water (wire lubricant solution), a solution of fatty acid amine in a concentration of 100 weight ppm was used.

The wire thus obtained was subjected to a sliding resistance test, and a bonding test for examining the bonding number until generation of an abnormal loop.

Additionally, in the present invention, the sliding resistance test was carried out in a severer condition as compared with the usual condition of the known test.

Namely, as shown in Fig.4, the wire 1 thus obtained was inserted in an alumina made capillary 20, and drawn from an outlet 20a at the lower end of the capillary at an angle θ of 80° relative to the vertical direction V. Subsequently, it was rewound using a rewinder 24 by way of a fixed roll 21, movable roll 22 and a fixed roll 23. A load cell 25 was attached to the movable roll 22, to measure the resistance of the rewound wire. The resistance of the wire which was rewound at a rewinding rate of 10 m/sec was measured at passing positions (100m, 1000m). The measured value was taken as the sliding resistance of the wire against the capillary 20.

The measured results are shown in Table 2.

The bonding test for measuring the bonding number until generation of an abnormal loop was carried out using a bonding machine sold by Niikawa Company under the trade name of 50 TYPE BONDER. After the initial ball bonding, the reverse deformation was performed by moving the capillary once in the direction reversed to the loop formation direction, and then a normal loop was formed. The bonding condition was as follows; loop height: 200 μm, loop length: 5 mm, loop mode: H, and reversed amount: 600 μm.

The bonding number until generation of an abnormal loop as the present subject was thus measured. The measured results are shown in Table 2.

(Inventive Examples 2 to 10, Comparative Examples 1 to 3)

Wires were manufactured and tested in the same manner as Inventive Example 1, except that the annealing furnace temperature, wire speed, distance between the outlet of the annealing furnace and the cooling water surface, kind of the wire lubricant as cooling water, concentration of wire lubricant in cooling water, and cooling rate were set as described in Table 1. The results are shown in Table 2.

(Inventive Example 11)

Wires were manufactured and tested in the same manner as in Inventive Example 3, except that the wire lubricant solution was not used as cooling water, and after final annealing and cooling, the wire was dipped in a solution of fatty acid amine in a concentration of 100 weight ppm as a separate wire lubricant coating process. The measured results are shown in Table 4.

[Table 1]

	Manufacturing condition (Wire lubricant solution, used for cooling water)					
	Annealing furnace temperature (°C)	Wire speed (m/min)	Distance between outlet of annealing furnace and cooling water surface(cm)	Wire lubricant	Concentration of lubricant in cooling water(*)	Cooling rate (°C/sec)
Inventive Example 1	420	60	40	Fatty acid amine	100	1,000
2	420	60	20	Fatty acid amine	100	2,000
3	420	60	4	Fatty acid amine	100	10,000
4	320	60	3	Fatty acid amine	100	10,000
5	620	60	6	Fatty acid amine	100	10,000
6	420	30	2	Fatty acid amine	100	10,000
7	420	60	4	Fatty acid amine	10	10,000
8	420	60	4	Fatty acid amine	300	10,000
9	420	60	4	Fatty acid diester	100	10,000
10	420	60	1.3	Fatty acid amine	100	30,000
Comparative Example 1	420	60	100	Fatty acid amine	100	400
2	620	60	100	Fatty acid amine	100	600
3	420	60	100	—	—	400

* Unit of concentration of lubricant in cooling water: weight ppm

[Table 2]

	Measured result		
	Sliding resistance (g)		Bonding number (times) until generation of abnormal loop
	100m	1000m	
Inventive Example 1	4.0	4.1	5×10^5
2	3.3	3.5	8×10^5
3	2.8	2.9	8×10^5
4	2.9	3.0	8×10^5
5	2.9	3.0	8×10^5
6	2.7	2.8	8×10^5
7	3.1	3.2	8×10^5
8	3.0	3.1	8×10^5
9	2.8	2.9	8×10^5
10	2.8	2.9	8×10^5
Comparative Example 1	4.6	4.8	4×10^4
2	4.6	4.8	4×10^4
3	5.8	6.0	10^3

[Table 3]

	Manufacturing condition (coating of wire lubricant after annealing and cooling)					
	Annealing furnace temperature (°C)	Wire speed (m/min)	Distance between outlet of annealing furnace and cooling water surface (cm)	Cooling rate (°C/sec)	wire lubricant	Concentra-tion of lubricant in cooling water(*)
Inventive Example 11	420	60	4	10,000	Fatty acid amine	100

* Unit of concentration of lubricant in cooling water: weight ppm

[Table 4]

	Measure result		
	Sliding resistance (g)		Bonding number (times) until generation of abnormal loop
	100m	1000m	
Inventive Example 11	3.1	3.2	8×10^5

From the Tables 1 to 4, the following results can be obtained. With respect to the wires obtained by the manufacturing methods in Inventive Examples 1 to 11 in which the wires after final annealing are cooled with cooling water at a cooling rate of 1000°C/sec or more, the bonding number until generation of an abnormal loop is 5×10^5 times or more even in the case of the severe loop formation by reversed deformation, thus significantly reducing the exchange frequency of a capillary.

With respect to the wires obtained by the manufacturing methods in Inventive Examples 2 to 11 in which the cooling rate is 2000°C/sec or more, the bonding number until generation of an abnormal loop is 8×10^5 times or more, thus further reducing the exchange frequency of a capillary. On the contrary, with respect to the wires obtained by the manufacturing methods in Comparative Examples 1 and 2 in which the cooling rate is 1000°C/sec or less, the bonding number until generation of abnormal loop is 4×10^4 times, and consequently, these wires are improved as compared with that in Comparative Example 3 but are insufficient in effect as compared with those in Inventive Examples.

With respect to the wire obtained by the manufacturing method in Comparative Example 3, the bonding number is 10^3 times, and thereby the exchange frequency of a capillary is significantly high.

As described above, according to the manufacturing method in claim 1, the adhesiveness of wire lubricant against a wire can be increased by specifying the cooling rate at 1000°C/sec. Accordingly, with respect to the wire thus obtained, wire lubricant is difficult to be separated from the wire, that is, difficult to be stuck on the capillary as foreign matters even in the case of loop formation in a severe mode of reverse deformation, thereby reducing the resistance between the wire and the capillary. This makes it possible to significantly increase the bonding number until generation of an abnormal loop as compared with the conventional manner, and hence to significantly reduce the exchange frequency of an expensive capillary of the bonding machine.

The invention described in claim 1, therefore, is preferably applied to a method of manufacturing a bonding wire allowing the bonding mounting work in manufacture of semiconductor devices to be effectively performed at a low cost.

According to the manufacturing method described in claim 2, the adhesiveness of wire lubricant against a wire can be further increased by specifying the cooling rate defined in claim 1 at 2000°C/sec or more. Accordingly, the wire obtained by this method is effective to further increase the bonding number until generation of an abnormal loop, and hence to further significantly reduce the exchange frequency of a capillary.

The invention defined in claim 2, therefore, can increase the effect more than the invention described in claim 1.

According to the manufacturing method described in claims 3 or 4, since wire lubricant solution is used as cooling water, the coating of the wire lubricant can be performed together with the cooling at a cooling rate ranging from 1000°C/sec to 2000°C/sec directly after final annealing; consequently, in addition to the excellent effects by the methods described in claims 1 or 2, there presents an advantage in that the processes can be shortened as compared with the case where the coating of the wire lubricant is separately performed after cooling.

[Second Means]

Next, the manufacturing method described in claims 5 and 6, in which the second means is used to increase the adhesiveness of wire lubricant against a wire, will be described. Specifically, in this second means, the drawing is performed using water soluble lubricant generally used for cold working, and the coating of wire lubricant on the wire is performed by dipping the rewound wire in wire lubricant solution, and taking-out the wire from the solution at an angle between the wire taking-out direction and the wire lubricant solution surface which is specified at 50-60°.

In this manufacturing method, an ingot of a metal or an alloy having a specified composition prepared by melting and casting is subjected to plastic working such as rolling or extrusion, and is repeatedly subjected to drawing using water soluble lubricant for cold working and intermediate annealing, to prepare an intermediate wire; the intermediate wire is finally drawn, to prepare a wire having a specified diameter; the wire is then cleaned and finally annealed, and after cooling, it is dipped in wire lubricant solution while being rewound from a rewinder and is taken-out from the solution at an angle between the wire taking-out direction and the wire

lubricant solution surface specified at 50 to 60°C, to be thus coated with the wire lubricant.

In this manufacturing method, during drawing using a die or the like, water soluble lubricant must be used at least as the cold working lubricant in the final drawing. In the case of drawing using oil lubricant or solid lubricant, it is difficult to significantly increase the bonding number until generation of an abnormal loop, which is the present subject, even by coating the wire decreased in the cleaning process as the post-treatment with wire lubricant

Here, the water-soluble lubricant contains water, oil and surface active agent, and may be added with an oiliness improver and extreme-pressure additive.

By performing cleaning, final annealing, cooling and wire lubricant coating for the wire after drawing it using the water-soluble lubricant for cold working, the bonding number until generation of an abnormal loop, which is the present subject, can be increased.

In this manufacturing method, after the final drawing, cleaning as post-treatment must be performed for removing the water-soluble lubricant.

At this time, the temperature of a cleaning bath is preferably kept at 90-100°C.

By coating the wire with wire lubricant under the following condition after cleaning it at the above-described temperature, the bonding number until generation of an abnormal loop, which is the present subject, can be significantly increased.

As the wire lubricant used in this manufacturing method, an fat and oil series lubricant capable of coating the surface of a wire with organic carbon is preferably used, similarly to [First Means]. In particular, a fatty acid series synthetic oil is preferably used for increasing the adhesiveness against the wire.

One example of the process of coating a wire with wire lubricant according to this manufacturing method will be described with reference to Fig. 3. A wire 1 cleaned in the above-described manner after final drawing is rewound from a rewinder 10, and is finally annealed in an annealing furnace 11. Subsequently, it is introduced in a lubricant solution bath 15 filled with wire lubricant 16 by way of a first roller 12, to be thus dipped in the wire lubricant 16.

The wire 1 is then introduced to a second roller 13, and is taken out from the lubricant solution bath 15 at an angle θ between the taking-out direction and the

solution surface 16a of the wire lubricant 16, after which it is rewound around a rewinder 17 by way of a third roller 14.

According to this manufacturing method, in the process of coating the wire with wire lubricant, the angle θ between the taking-out direction of the wire from the solution of the wire lubricant 16 and the solution surface 16a is required to be in the range of from 50 to 60°. With this taking-out angle of the wire from the solution, it is possible to significantly increase the bonding number until generation of an abnormal loop, which is the present subject, even in the case of forming a normal loop after reverse deformation.

Conventionally, the taking-out angle of the wire from the solution has been set at 70° or more for making compact the size of the equipment. However, when the taking-out angle of the wire is more than 60°, or less than 50°, the effect of increasing the bonding number until generation of an abnormal loop, which is the present subject, is insufficient yet. Accordingly, the taking-out angle of the wire is specified in the range of from 50 to 60°.

In this manufacturing method, the thickness of the wire lubricant coated on the wire surface is preferably

set in the range of from 1 to 30 Å (10^{-10} m) for achieving the present subject. The thickness of the wire lubricant can be controlled by adjustment of the concentration of the lubricant used for coating the wire.

The reason why the manufacturing method having the above-described construction is effective for achieving the present subject, is unclear; however, the effect seems to be due to the increased adhesiveness between a wire and wire lubricant.

Namely, in the case where the adhesiveness between a wire and wire lubricant is high, even by forming a loop by a severe mode such as reverse deformation, the wire lubricant is difficult to be separated from the wire, and to be stuck on a capillary. This is effective to reduce the resistance between the wire and the capillary, and to prevent the generation of a trouble such as an abnormal loop, which is the present subject, thus reducing the exchange frequency of the capillary.

The second means will be more clearly understood with reference to the inventive examples and comparative examples shown in Table 5.

(Inventive Example 12)

An ingot (diameter: 30 mm) of a Au alloy containing Y in an amount of 40 weight ppm was rolled between grooved rolls, and then repeatedly subjected to drawing by a die or the like using water-soluble lubricant for cold working and intermediate annealing, and finally drawn, to obtain a wire having a diameter of 25 μm. The wire was rewound from a rewinder, and was cleaned by passing it in water at a temperature of 95°C as post-treatment, and finally annealed in an annealing furnace such that the elongation percentage ratio become 4%, after which it was cooled (air-cooling) in a usual manner. Subsequently, the wire was coated with wire lubricant by dipping the wire in a solution of fatty acid amine diluted with water in a concentration of 100 weight ppm and taking-out it from the solution at an angle (θ shown in Fig. 3) between the taking-out direction from the solution and the solution surface which was specified at 50°, and was rewound around a rewinder.

The wires thus obtained was subjected to the same bonding test as in Inventive Example 1 for measuring the bonding number until generation of an abnormal loop. The measured results are shown in Table 6.

(Inventive Examples 13 to 21, Comparative Examples 4 to 10)

Wires were manufactured in the same manner as Inventive Example 12, except that materials of wires, cleaning temperature, taking-out angle against wire lubricant solution surface were set as described in Table 5, and were subjected to bonding test. The measured results are shown in Table 6.

[Table 5]

	Manufacturing condition			
	Wire material	Cleaning temperature (°C)	Wire lubricant	Angle against wire lubricant solution surface
Inventive Example 12	Au-Y	95	Fatty acid amine	50°
13	Au-Y	95	Fatty acid amine	55°
14	Au-Y	95	Fatty acid amine	60°
15	Au-Y	20	Fatty acid amine	55°
16	Au-Y	80	Fatty acid amine	55°
17	Au-Y	90	Fatty acid amine	55°
18	Au-Y	100	Fatty acid amine	55°
19	Al-Si	95	Fatty acid amine	55°
20	Cu	95	Fatty acid amine	55°
21	Au-Y	95	Fatty acid diester	55°
Comparative Example 4	Au-Y	95	Fatty acid amine	20°
5	Au-Y	95	Fatty acid amine	40°
6	Au-Y	95	Fatty acid amine	70°
7	Au-Y	95	Fatty acid amine	90°
8	Au-Y	95	Fatty acid diester	20°
9	Au-Y	95	—	—
10	Au-Y	20	—	—

[Table 6]

	Measured result
	Bonding number until generation of abnormal loop (times)
Inventive Example 12	7×10^5
13	7×10^5
14	7×10^5
15	5×10^5
16	5×10^5
17	7×10^5
18	7×10^5
19	7×10^5
20	7×10^5
21	7×10^5
Comparative Example 4	4×10^4
5	4×10^4
6	4×10^4
7	4×10^4
8	4×10^4
9	10^4
10	10^3

Comparative Example

From Tables 5 and 6, the following results can be obtained. With respect to the wires obtained by the manufacturing methods in Inventive Examples 12 to 21 in which the drawing is performed using water-soluble lubricant for cold working and an angle between the wire taking-out direction from the wire lubricant solution and the wire lubricant solution surface is set at a value ranging from 50 to 60°, the bonding number until generation of an abnormal loop is 5×10^5 times or more even in the case of the severe loop formation by reversed deformation, thus significantly reducing the exchange frequency of a capillary.

With respect to the wires obtained in Inventive Examples 12 to 14, and 17 to 21 in which the cleaning temperature in the cleaning process as the post-treatment is set at a value ranging from 90 to 100°C, the bonding number until generation of an abnormal loop is 7×10^5 times or more, thus further reducing the exchange frequency of a capillary.

On the contrary, with respect to the wire obtained in Comparative Example 9 in which the cleaning temperature in the cleaning process as the post-treatment is in the specified range of the present

invention but the coating of wire lubricant is not performed, the bonding number until generation of an abnormal loop is 10^4 times. Moreover, with respect to the wire obtained in Comparative Example 10 in which the cleaning temperature is out of the range of the present invention and the coating of wire lubricant is not performed, the bonding number until generation of an abnormal loop is 10^3 times, thus extremely increasing the exchange frequency of a capillary.

With respect to the wires obtained in Comparative Examples 4 to 8 in which the cleaning temperature in the cleaning process as the post-treatment is out of the range of the present invention, and the coating of wire lubricant is performed by dipping it in a wire lubricant solution and taking-out it from the solution at an angle between the wire taking-out direction and the wire lubricant solution surface, which is out of the range of the present invention, the bonding number until generation of an abnormal loop is 4×10^4 times, which is improved as compared with the wires in Comparative Examples 9 and 10 but is insufficient in effect as compared with the wires of the present invention.

As described above, according to the manufacturing method described in claim 5, the adhesiveness of wire

lubricant against a wire can be increased by drawing the wire using water soluble lubricant for cold working and specifying the angle between the taking-out direction of the wire from the wire lubricant solution surface and the wire lubricant solution surface at 50-60°. Accordingly, in the wire thus obtained, wire lubricant is difficult to be separated from the wire, that is, being difficult to be stuck on the capillary as foreign matters even in the case of loop formation of a severe mode of reverse deformation, thereby reducing the resistance between the wire and the capillary. This makes it possible to significantly increase the bonding number until generation of an abnormal loop as compared with the conventional manner, and hence to significantly reduce the exchange frequency of an expensive capillary of the bonding machine.

The invention described in claim 5, therefore, is preferably applied to a method of manufacturing a bonding wire enabling the bonding mounting work in manufacture of semiconductor devices to be effectively performed at a low cost.

According to the manufacturing method described in claim 6, the adhesiveness of wire lubricant against a wire can be further increased by specifying the cleaning

temperature in the cleaning process as the post-treatment at 90-100° in the method described in claim 5. Accordingly, the wire obtained by the method makes it possible to further increase the bonding number until generation of an abnormal loop, and hence to further reduce the exchange frequency of a capillary.

The invention described in claim 6, therefore, can further enhance the effect of the invention described in claim 5.

[Third Means]

Next, a manufacturing method as described in claims 7 to 9, in which the third means is used for increasing the adhesiveness of wire lubricant, that is, an intermediate wire obtained by drawing is subjected to surface layer removing treatment, will be described.

In this manufacturing method, an ingot of a metal or an alloy having a specified composition prepared by melting and casting is subjected to plastic working such as rolling or extrusion, and is repeatedly subjected to drawing using water soluble lubricant for cold working and intermediate annealing, to prepare an intermediate wire; the intermediate wire is subjected to surface layer removing treatment and is finally drawn, to prepare a wire having a desired diameter; and the

resultant wire is cleaned and finally annealed, and after cooling, it is coated with wire lubricant.

The wording "intermediate wire" means the wire in the stage from plastic working of an ingot to final drawing.

The intermediate wire is manufactured, for example, in the following processes.

An ingot (diameter: 20-50 mm) of a metal or an alloy by melting and casting is subjected to semi-finish working by rolling using grooved rolls, to prepare a wire having an unspecified shape in cross-section. The semi-finished wire is drawn in a diameter of 1-5 mm, and the resultant wire is further drawn, to thus obtain an intermediate wire having a specified diameter.

In this manufacturing method, the surface layer removing treatment may be applied to the intermediate wire in any stage from the state of semi-finish working by rolling using grooved rolls to the state prior to final drawing; however, it is desirable for achieving the present subject to reduce the number of annealing after the surface layer removing treatment.

Most preferably, the surface layer removing treatment may be applied to the intermediate wire after the final intermediate annealing.

The present inventors have found the fact that the bonding wire, which is obtained by a method wherein an intermediate wire is subjected to the surface layer removing treatment, and then subjected to drawing, annealing, wire lubricant coating according to the conventional manner, is very effective for achieving the present subject, and accomplished this manufacturing method.

The specific examples of the surface layer removing methods include etching, peeling, and buff polishing.

Of these methods, etching is preferably used.

Namely, the intermediate wire according to this manufacturing method has a relatively long size coil shape, and accordingly etching is desirable to uniformly apply the surface layer removing treatment to the intermediate wire.

As an etching solution used in the etching process of this manufacturing method, there may be used acid such as aqua regia, nitrate or ferric chloride; and alkali such as sodium cyanide.

The above-described etching solution may be added with a surface active agent as an additive, which is more effective to achieve the present subject.

For example, an etching solution of aqua regia diluted with water which is added with fluorine series surface active agent in an amount of 0.05 to 0.5% is preferably used for etching of a gold wire.

The reason why the surface layer removing treatment for an intermediate is effective for achieving the present subject is unclear; however, it seems that foreign matters present on the surface of the intermediate wire are sufficiently removed by the surface layer removing treatment, and thereby in the subsequent wire lubricant coating process, the adhesiveness between the wire and wire lubricant becomes higher.

Namely, in process of working an ingot up to an intermediate wire, foreign matters such as oxides formed on the surface on the ingot upon casting and lubricating oil for cold working used for working the ingot are stuck on the surface of the intermediate wire.

By removing these foreign matters or oils from the intermediate wire, the adhesiveness between the finally drawn wire and wire lubricant can be enhanced, which is effective for achieving the present subject.

The intermediate wire is drawn in a specified diameter, and is subjected to intermediate annealing, as

needed. And, as described above, the surface layer removing treatment is preferably applied to the intermediate wire after final intermediate annealing.

In this manufacturing method, it is desirable to use water soluble lubricant for drawing after the surface layer removing treatment. The wire drawn using such water soluble lubricant is preferably dipped in a water bath and cleaned for removing the lubricant, before final annealing.

As the wire lubricant used in this manufacturing method, a fat and oil series lubricant capable of coating the wire surface with organic carbon is preferably used, similarly to the first means. In particular, a fatty acid series synthetic oil is preferably used for increasing the adhesiveness against a wire.

A wire is dipped in a solution of the above-described wire lubricant diluted with water, to be coated with the wire lubricant. The thickness of wire lubricant coated on the surface of a wire is preferably in the range of from 1 to 30 Å (10^{-10} m). The film thickness can be controlled by adjustment of the concentration of wire lubricant diluted with water.

The third means will be more clearly understood with reference to inventive examples and comparative examples shown in Table 7.

(Inventive Example 22)

An ingot (diameter: 30 mm) of a Au alloy containing Y in an amount of 40 weight ppm was rolled between grooved rolls into an irregular shapes wire having an outside diameter of 5 mm. The irregular shaped wire was repeatedly subjected to intermediate annealing, drawing and intermediate annealing, to prepare an intermediate wire having a diameter of 1 mm. The intermediate wire was subjected to surface layer removing treatment by etching. An etching solution (aqua regia diluted with water at a volume ratio of 1:1) added with 0.05% of a fluorine series surface active agent was used. The wire was cleaned by water and dried, and drawn using water soluble lubricant, to prepare a wire having a diameter of 25 μm. The resultant wire was cleaned by water and finally annealed such that the elongation percentage become 4%, and was cooled (air cooling) by the usual manner. Subsequently, the wire was dipped in solution of fatty acid amine in a concentration of 100 weight ppm while being rewound from a rewinder, to be thus coated with wire lubricant.

The wires thus obtained were subjected to sliding resistance test and bonding test for examining bonding number until generation of an abnormal loop in the same manner as in Inventive Example 1. The measured results are shown in Table 8.

(Inventive Examples 23 to 27)

Wires were manufactured and tested in the same manner as in Inventive Example 22 except that wire materials and etching conditions were set as described in Table 7. The measured results are shown in Table 8.

(Inventive Examples 28 and 29)

Wires were manufactured and tested in the same manner as in Inventive Example 22 except that etching was replaced with peeling or buff polishing as shown in Table 7. The measured results are shown in Table 8.

(Comparative Examples 11 and 12)

Wires were manufactured and tested in the same manner as in Inventive Example 22 except that the surface layer removing treatment of an intermediate wire was not performed. The measured results are shown in Table 8.

[Table 7]

	Manufacturing condition					
	Wire material	Surface layer removing method	Etching condition			Presence or absence of wire lubricant coating
			Main solution	Surface active agent		
				Kind	(wt%)	
Inventive Example 22	Au-Y	Etching	Aqua regia	Fluorine series	0.05	Presence
23	Au-Y	Etching	Aqua regia	Fluorine series	0.1	Presence
24	Au-Y	Etching	Aqua regia	Fluorine series	0.5	Presence
25	Au-Y	Etching	Aqua regia	—	—	Presence
26	Au-Y	Etching	Aqua regia	Water soluble series	0.1	Presence
27	Cu	Etching	Nitrate	Fluorine series	0.1	Presence
28	Au-Y	Peeling	—	—	—	Presence
29	Au-Y	Buff polishing	—	—	—	Presence
Comparative Example 11	Au-Y	—	—	—	—	Presence
12	Au-Y	—	—	—	—	Absence

[Table 8]

	Measured result		
	Sliding resistance(g)		Bonding number (times) until generation of abnormal loop
	100m	1000m	
Inventive Example 22	3.4	3.5	10^6 or more
23	2.7	2.8	10^6 or more
24	3.1	3.2	10^6 or more
25	4.0	4.1	9×10^5
26	2.8	2.9	10^6 or more
27	3.1	3.2	10^6 or more
28	4.3	4.4	5×10^5
29	4.3	4.4	5×10^5
Comparative Example 11	4.6	4.8	4×10^4
12	5.8	6.0	10^3

From Table 7 and 8, the following results can be obtained. With respect to the wires obtained in Inventive Examples 22 to 29 in which an intermediate wire obtained by plastic working of an ingot is subjected to surface layer removing treatment, the bonding number until generation of an abnormal loop is 5×10^5 times or more, thereby significantly reducing the exchange frequency of a capillary.

With respect to the wires obtained in Inventive Examples 22 to 27 in which the surface layer removing treatment is performed by etching, the bonding number until generation of an abnormal loop is 9×10^5 times or more, thereby further reducing the exchange frequency of a capillary.

With respect to the wires obtained in Inventive Examples 22 to 24, 26 and 27 in which an etching solution containing a surface active agent is used for the above-described etching, the bonding number until generation of an abnormal loop is 10^6 or more, thereby further reducing the exchange frequency of a capillary.

On the contrary, with respect to the wire in Comparative Example 12 in which the intermediate wire is not subjected to surface layer removing treatment and coating of wire lubricant is not performed after final

annealing, the bonding number until generation of an abnormal loop is 10^3 times, thereby extremely increasing the exchange frequency of a capillary.

With respect to the wire in Comparative Example 11 in which coating of wire lubricant is performed after final annealing but the intermediate wire is not subjected to surface layer removing treatment, the bonding number until generation of an abnormal loop is 4×10^4 times, which is improved as compared with the wire in Comparative Example 12 but is insufficient as compared with the wires in Inventive Examples.

As described above, according to the manufacturing method in claim 7, the adhesiveness of wire lubricant against a wire can be increased in the wire lubricant coating process as the post-treatment by applying the surface layer removing treatment to the intermediate wire obtained by plastic working of an ingot. Accordingly, with respect to the wire thus obtained, wire lubricant is difficult to be separated from the wire, that is, difficult to be stuck on the capillary as foreign matters even in the case of loop formation in a severe mode of reverse deformation, thereby reducing the resistance between the wire and the capillary. This makes it possible to significantly increase the bonding

number until generation of an abnormal loop as compared with the conventional manner, and hence to significantly reduce the exchange frequency of an expensive capillary of the bonding machine.

The invention described in claim 7, therefore, is preferably applied to a method of manufacturing a bonding wire allowing the bonding mounting work in manufacture of semiconductor devices to be effectively performed at a low cost.

According to the manufacturing method described in claim 8, the adhesiveness of wire lubricant against a wire can be further increased by performing the surface layer removing treatment in claim 7 by etching. Accordingly, the wire obtained by this method is effective to further increase the bonding number until generation of an abnormal loop, and hence to further significantly reduce the exchange frequency of a capillary.

The invention defined in claim 8, therefore, can further enhance the effect of the invention described in claim 7.

According to the manufacturing method described in claim 9, by using an etching solution containing a surface active agent as an additive in the etching

process described in claim 8, the adhesiveness of wire lubricant against a wire can be further increased. Accordingly, the wire obtained in this method makes it possible to further reduce the exchange frequency of a capillary.

The invention described in claim 9, therefore, can enhance the effect of the invention described in claim 8.

[Fourth Means]

Next, the manufacturing method described in claims 10 to 13, in which the above-described first and second means are used for increasing the adhesiveness of wire lubricant, will be described. Specifically, in the fourth means, a wire is drawn using water soluble lubricant for cold working; the wire after final annealing is cooled at a cooling rate of 1000°C/sec or more; and in a wire lubricant coating process, an angle between the wire taking-out direction and the wire lubricant solution surface is specified at 50-60°.

In this manufacturing method, an ingot of a metal or an alloy having a specified composition prepared by melting and casting is subjected to plastic working such as rolling or extrusion, and repeatedly subjected to drawing using water soluble lubricant for cold working

and intermediate annealing, to prepare an intermediate wire; the intermediate wire is finally drawn, to prepare a wire having a specified diameter; and the resultant wire is cleaned and finally annealed, being directly cooled with cooling water at a cooling rate of 1000°C/sec or more, and after cooling (or during cooling), it is coated with wire lubricant.

In the above-described wire lubricant coating process, the wire is dipped in wire lubricant solution while being rewound from a rewinder, and is taken out from the solution. In this case, at an angle between the taking-out direction and the wire lubricant solution surface must be specified at 50-60°.

The details of this manufacturing method is the same as that described in [First Means] except for the wire lubricant coating process and the wire lubricant coating process is the same as that described in [Second Means], and therefore, the explanation thereof is omitted.

The fourth means will be more clearly understood with reference to inventive examples shown in Tables 9 and 11.

(Inventive Example 30)

An ingot (diameter: 30 mm) of a Au alloy containing Y in an amount of 40 weight ppm was rolled between grooved rolls, being repeatedly subjected to drawing by a die using water soluble lubricant for cold working and intermediate annealing, and finally drawn, to prepare a wire having a diameter of 25 μm. The resultant wire was subjected to cleaning as post-treatment by passing it through a water at a temperature of 95°C, and was finally annealed in an annealing furnace such that the elongation percentage become 4%. The cooling after annealing was performed using wire lubricant as cooling water, thus performing the cooling together with the coating of wire lubricant. The coating of wire lubricant was performed by dipping the wire in wire lubricant solution composed of fatty acid amine solution diluted with water in a concentration of 100 weight ppm, and taking out the wire from the solution at an angle between the taking-out direction of the wire from the solution and the solution surface, which was specified at 50°. The wire thus taken out from the solution was wound using a winder. At this time, the annealing furnace temperature (atmospheric temperature in the annealing furnace) was set at 420°C; the wire speed was 60 m/min; the distance between an outlet of the

annealing furnace and a cooling water surface was 40 cm; and the cooling water temperature (temperature of the wire lubricant solution) was 20°C. Also, the wire was annealed by adjusting the length of the heating zone in the annealing furnace such that the elongation percentage become 4%. The cooling rate was 1000°C/sec. As the cooling water (wire lubricant solution), a solution of fatty acid amine in a concentration of 100 weight ppm was used.

The wires thus obtained were subjected to bonding test in the same manner as in Inventive Example 1. The measured results are shown in Table 10.

(Inventive Examples 31 to 44)

Wires were manufactured and tested in the same manner as in Inventive Example 30 except that the kind of wire lubricant, cooling rate, cleaning temperature, and angle against wire lubricant solution surface were set as described in Table 9. The measured results are shown in Table 10.

(Inventive Example 45)

Wires were manufactured and tested in the same manner as in Inventive Example 31 except that wire lubricant solution was not used as cooling water, and a wire was cooled in the usual manner (air cooling) after

final annealing and in a separate wire lubricant coating process, it was made to pass through solution of fatty acid amine in a concentration of 100 weight ppm. The measured results are shown in Table 12.

(Inventive Example 46)

A wire was manufactured and tested in the same manner as in Inventive Example 45 except that the cooling rate was set as described in Table 11. The measured results are shown in Table 12.

[Table 9]

	Manufacturing condition (Wire lubricant solution, used for cooling water)							
	Annealing furnace temperature (°C)	Wire speed (m/min)	Distance between outlet of annealing furnace and cooling water surface (cm)	Wire lubricant	Concentration of lubricant in cooling water(*)	Cooling rate (°C/sec)	Cleaning temperature (°C)	Taking-out angle against wire lubricant solution surface
Inventive Example 30	420	60	40	Fatty acid amine	100	1,000	95	50°
31	420	60	40	Fatty acid amine	100	1,000	95	55°
32	420	60	40	Fatty acid amine	100	1,000	95	60°
33	420	60	40	Fatty acid amine	100	1,000	20	55°
34	420	60	40	Fatty acid amine	100	1,000	80	55°
35	420	60	40	Fatty acid amine	100	1,000	90	55°
36	420	60	40	Fatty acid amine	100	1,000	100	55°
37	420	60	40	Fatty acid diester	100	1,000	95	55°
38	420	60	40	Fatty acid amine	100	2,000	95	50°
39	420	60	40	Fatty acid amine	100	2,000	95	55°
40	420	60	40	Fatty acid amine	100	2,000	95	60°
41	420	60	40	Fatty acid amine	100	2,000	20	55°
42	420	60	40	Fatty acid amine	100	2,000	80	55°
43	420	60	40	Fatty acid amine	100	2,000	90	55°
44	420	60	40	Fatty acid amine	100	2,000	100	55°

* Unit of concentration of lubricant in cooling water: weight ppm

[Table 10]

	Measured result
	Bonding number (times) until generation of abnormal loop
Inventive Example 30	9×10^5
31	9×10^5
32	9×10^5
33	8×10^5
34	8×10^5
35	9×10^5
36	9×10^5
37	9×10^5
38	10^6 or more
39	10^6 or more
40	10^6 or more
41	9×10^5
42	9×10^5
43	10^6 or more
44	10^6 or more

[Table 11]

	Manufacturing condition (Coating of wire lubricant after annealing and cooling)							
	Annealing furnace temperature (°C)	Wire speed (m/min)	Distance between outlet of annealing furnace and cooling water surface (cm)	Cooling rate (°C/sec)	Wire lubricant	Concentration of lubricant in cooling water(*)	Cleaning temperature (°C)	Taking-out angle against wire lubricant solution surface
Inventive Example 45	420	60	40	1,000	Fatty acid amine	100	95	55°
Inventive Example 46	420	60	20	2,000	Fatty acid amine	100	95	55°

* Unit of concentration of wire lubricant: weight ppm

[Table 12]

	Measured result
	Bonding number (times) until generation of abnormal loop
Inventive Example 45	9×10^5
Inventive Example 46	10^6 or more

From Tables 9 to 12, the following results can be obtained. With respect to the wires obtained in Inventive Examples 33 and 34 in which the first means (cooling rate: 1000°C/sec or more) and the second means (the drawing is performed using water soluble lubricant for cold working and in the coating of wire lubricant, an angle between the wire taking-out direction and the wire lubricant solution surface is specified at 50-60°) are used for increasing the adhesiveness of wire lubricant, the bonding number until generation of an abnormal loop is 8×10^5 times even in the case of severe loop formation by reverse deformation, thus obtaining the effect superior to that in the case including either of the first and second means (Inventive Examples 1, 15 and 16).

With respect to the wires obtained in Inventive Examples 41 and 42 in which the above-described cooling rate is 2000°C/sec or more, the bonding number until generation of an abnormal loop is 9×10^5 times, thereby obtaining the effect superior to that in the case where the cooling rate is 2000°C/sec or more but the second means is not provided (Inventive Examples 2 to 11).

With respect to the wires obtained in Inventive Examples 30 to 32 and 35 to 37, and 45 in which the

cleaning temperature in the cleaning process as post-treatment is set as 90-100°C, the bonding number until generation of an abnormal loop is 9×10^5 times, and further with respect to the wires obtained in Inventive Examples 40, 43, 44 and 46 in which the cleaning temperature is set as 90-100°C, the bonding number until generation of an abnormal loop is 106 times or more, thereby obtaining the effect superior to that in the case where the cleaning temperature is out of the range of from 90 to 100°C (Inventive Examples 33, 34, 41, 42).

As described above, according to the manufacturing method in claim 10, the adhesiveness of wire lubricant against a wire can be increased by drawing a wire using water soluble lubricant for cold working, cooling the wire directly after final annealing at a cooling rate of 1000°C/sec or more, and specifying an angle between the taking-out direction and the wire lubricant solution surface in the wire lubricant coating process at 50-60°. Accordingly, with respect to the wire thus obtained, wire lubricant is difficult to be separated from the wire, that is, difficult to be stuck on the capillary as foreign matters even in the case of loop formation in a severe mode of reverse deformation, thereby reducing the resistance between the wire and the capillary. This

makes it possible to significantly increase the bonding number until generation of an abnormal loop as compared with the conventional manner, and hence to significantly reduce the exchange frequency of an expensive capillary of the bonding machine.

The invention described in claim 10, therefore, is preferably applied to a method of manufacturing a bonding wire allowing the bonding mounting work in manufacture of semiconductor devices to be effectively performed at a low cost.

According to the manufacturing method described in claim 12, the adhesiveness of wire lubricant against a wire can be increased by specifying the cooling rate described in claim 10 at 2000°C/sec or more. The wire thus obtained makes it possible to further increase the bonding number until generation of an abnormal loop, and hence to further reduce the exchange frequency of a capillary.

The invention described in claim 12, therefore, can enhance the effect of the invention described in claim 10.

According to the manufacturing method described in claim 11 or 13, the adhesiveness of wire lubricant against a wire can be increased by specifying the

cleaning temperature in the cleaning process as post-treatment at 90-100°C. The wire thus obtained makes it possible to further increase the bonding number until generation of an abnormal loop, and hence to further reduce the exchange frequency of a capillary.

The invention described in claim 11 or 13, therefore, can enhance the effect of the invention described in claim 10 or 12.

[Fifth Means]

Next, the manufacturing method described in claim 14, in which the above-described first, second and third means are used for increasing the adhesiveness of wire lubricant, will be described. Specifically, in the fifth means, a wire is drawn using water soluble lubricant for cold working; an intermediated wire is subjected to surface layer removing treatment; the wire after final annealing is cooled at a cooling rate of 1000°C/sec or more; and in a wire lubricant coating process, an angle between the wire taking-out direction and the wire lubricant solution surface is specified at 50-60°.

In this manufacturing method, an ingot of a metal or an alloy having a specified composition prepared by melting and casting is subjected to plastic working such

as rolling or extrusion, and repeatedly subjected to drawing using water soluble lubricant for cold working and intermediate annealing, to prepare an intermediate wire; the intermediate wire is subjected to surface layer removing treatment and finally drawn, to prepare a wire having a specified diameter; and the resultant wire is cleaned and finally annealed, being directly cooled with cooling water at a cooling rate of 1000°C/sec or more, and after cooling (or during cooling), it is coated with wire lubricant.

In the above-described wire lubricant coating process, the wire is dipped in wire lubricant solution while being rewound from a rewinder, and is taken out from the solution. In this case, at an angle between the taking-out direction and the wire lubricant solution surface must be specified at 50-60°.

The details of this manufacturing method is the same as that described in [First Means] except for the surface layer removing treatment process and the wire lubricant coating process, and the wire lubricant coating process is the same as that described in [Second Means] and the surface layer removing treatment process is the same as that described in [Third Means], and therefore, the explanation thereof is omitted.

The fifth means will be more clearly understood with reference to inventive examples shown in Tables 13 and 15.

(Inventive Example 47)

An ingot (diameter: 30 mm) of a Au alloy containing Y in an amount of 40 weight ppm was rolled between grooved rolls into an irregular shaped wire having an outside diameter of 5 mm. The irregular shaped wire was repeatedly subjected to intermediate annealing, drawing and intermediate annealing, to prepare an intermediate wire having a diameter of 1 mm. The intermediate wire was subjected to surface layer removing treatment by etching. An etching solution (aqua regia diluted with water at a volume ratio of 1:1) added with a fluorine series surface active agent in an amount of 0.1% was used. The wire was cleaned by water and dried, and finally drawn using water soluble lubricant for cold working, to prepare a wire having a diameter of 25 μm. The resultant wire was subjected to cleaning as post-treatment by passing it through a water at a temperature of 95°C while being wound from a rewinder, and was finally annealed in an annealing furnace such that the elongation percentage become 4%. The cooling after annealing was performed using wire lubricant as cooling

water, thus performing the cooling together with the coating of wire lubricant. The coating of wire lubricant was performed by dipping the rewound wire in wire lubricant solution, and taking out the wire from the solution at an angle between the taking-out direction of the wire from the solution and the solution surface, which was specified at 50°. The wire thus taken out from the solution was wound using a winder. At this time, the annealing furnace temperature (atmospheric temperature in the annealing furnace) was set at 420°C; the wire speed was 60 m/min; the distance between an outlet of the annealing furnace and a cooling water surface was 40 cm; and the cooling water temperature (temperature of the wire lubricant solution) was 20°C. Also, the wire was annealed by adjusting the length of the heating zone in the annealing furnace such that the elongation percentage become 4%. The cooling rate was 1000°C/sec. As the cooling water (wire lubricant solution), a solution of fatty acid amine in a concentration of 100 weight ppm was used.

The wires thus obtained were subjected to bonding test in the same manner as in Inventive Example 1. The measured results are shown in Table 14.

(Inventive Examples 48 to 62)

Wires were manufactured and tested in the same manner as in Inventive Example 47 except that the annealing furnace temperature, wire speed, distance between the outlet of the annealing furnace and the cooling water surface, the kind of wire lubricant, cooling rate, cleaning temperature, angle against wire lubricant solution surface, surface layer removing method, and etching condition were set as described in Table 13. The measured results are shown in Table 14.

(Inventive Example 63)

Wires were manufactured and tested in the same manner as in Inventive Example 47 except that wire lubricant solution was not used as cooling water, and a wire was cooled in the usual manner (air cooling) after final annealing and in a separate wire lubricant coating process, it was made to pass through solution of fatty acid amine in a concentration of 100 weight ppm. The measured results are shown in Table 16.

(Inventive Example 64)

A wire was manufactured and tested in the same manner as in Inventive Example 63 except that the cooling rate was set as described in Table 15. The measured results are shown in Table 16.

[Table 13]

	Manufacturing condition (Wire lubricant solution, used for cooling water)										
	1)	2)	3)	4)	5)	6)	7)	8)	9)		
									10)	11)	
										12)	13)
Inventive Example 47	420	60	40	Fatty acid amine	1,000	95	55°	Etching	Aqua regia	Fluorine series	0.1
48	420	60	40	Fatty acid amine	1,000	95	55°	Etching	Aqua regia	Water soluble series	0.1
49	420	60	40	Fatty acid amine	1,000	95	55°	Etching	Nitrate	Fluorine series	0.1
50	420	60	40	Fatty acid amine	1,000	95	55°	Etching	Aqua regia	—	—
51	420	60	40	Fatty acid amine	1,000	95	55°	Peeling	—	—	—
52	420	60	40	Fatty acid amine	1,000	95	55°	Buff polishing	—	—	—
53	420	60	40	Fatty acid amine	1,000	20	55°	Etching	Aqua regia	Fluorine series	0.1
54	420	60	40	Fatty acid amine	1,000	80	55°	Etching	Aqua regia	Fluorine series	0.1
55	420	60	40	Fatty acid amine	1,000	95	50°	Etching	Aqua regia	Fluorine series	0.1
56	420	60	40	Fatty acid amine	1,000	95	60°	Etching	Aqua regia	Fluorine series	0.1
57	420	60	40	Fatty acid amine	1,000	90	55°	Etching	Aqua regia	Fluorine series	0.1
58	420	60	40	Fatty acid amine	1,000	100	55°	Etching	Aqua regia	Fluorine series	0.1
59	420	60	40	Fatty acid diester	1,000	95	55°	Etching	Aqua regia	Fluorine series	0.1
60	320	60	30	Fatty acid amine	1,000	95	55°	Etching	Aqua regia	Fluorine series	0.1
61	620	60	60	Fatty acid amine	1,000	95	55°	Etching	Aqua regia	Fluorine series	0.1
62	420	60	20	Fatty acid amine	2,000	95	55°	Etching	Aqua regia	Fluorine series	0.1

1) Annealing furnace temperature(°C) 2) Wire speed (m/min)
3) Distance between outlet of annealing furnace and cooling water surface(cm) 4) Wire lubricant
5) Cooling rate (°C/sec) 6) Cleaning temperature (°C)
7) Taking-out angle against wire lubricant solution surface
8) Surface layer removing method 9) Etching condition
10) Main solution 11) Surface active agent
12) Kind 13) (wt%)

[Table 14]

	Measured result
	Bonding number (times) until generation of abnormal loop
Inventive Example 47	10^6 or more
48	10^6 or more
49	10^6 or more
50	10^6 or more
51	10^6 or more
52	10^6 or more
53	10^6 or more
54	10^6 or more
55	10^6 or more
56	10^6 or more
57	10^6 or more
58	10^6 or more
59	10^6 or more
60	10^6 or more
61	10^6 or more
62	10^6 or more

[Table 15]

	Manufacturing condition (coating of wire lubricant after annealing and cooling)										
	1)	Wire speed (m/min)	2)	3)	Wire lubricant	4)	5)	Surface layer removing method	Etching condition		
									Main solution	6)	
										Kind	(wt%)
Inventive Example 63	420	60	40	1,000	Fatty acid amine	95	55°	Etching	Aqua regia	Fluorine series	0.1
Inventive Example 64	420	60	40	1,000	Fatty acid amine	95	55°	Etching	Aqua regia	Fluorine series	0.1

1) Annealing furnace temperature(°C)

2) Distance between outlet of annealing furnace and cooling water surface (cm)

3) Cooling rate(°C/sec)

4) Cleaning temperature(°C)

5) Taking-out angle against wire lubricant solution surface

6) Surface active agent

[Table 16]

	Measured result
	Bonding number (times) until generation of abnormal loop
Inventive Example 63	10^6 or more
Inventive Example 64	10^6 or more

From Tables 13 to 16, the following results can be obtained. With respect to the wires obtained in Inventive Examples 47 to 64 in which the first means (cooling rate: 1000°C/sec or more), the second means (the drawing is performed using water soluble lubricant for cold working and in the coating of wire lubricant, an angle between the wire taking-out direction and the wire lubricant solution surface is specified at 50-60°), and the third means (the intermediate wire is subjected to surface layer removing treatment) are used for increasing the adhesiveness of wire lubricant, the bonding number until generation of an abnormal loop is 106 times even in the case of severe loop formation by reverse deformation, thus obtaining the effect superior to that in Inventive Examples 1 to 21, 25, 28 to 37, 41, 42 and 45 and also obtaining the effect similar to or superior to that in Inventive Examples 22 to 24, 26, 27, 38 to 40, 43, 44 and 46.

As described above, according to the manufacturing method in claim 14, the adhesiveness of wire lubricant against a wire can be increased by applying surface layer removing treatment to an intermediate wire, drawing a wire using water soluble lubricant for cold working, cooling the wire directly after final annealing

at a cooling rate of 1000°C/sec or more, and specifying an angle between the taking-out direction and the wire lubricant solution surface in the wire lubricant coating process at 50-60°. Accordingly, with respect to the wire thus obtained, wire lubricant is difficult to be separated from the wire, that is, difficult to be stuck on the capillary as foreign matters even in the case of loop formation in a severe mode of reverse deformation, thereby reducing the resistance between the wire and the capillary. This makes it possible to significantly increase the bonding number until generation of an abnormal loop as compared with the conventional manner, and hence to significantly reduce the exchange frequency of an expensive capillary of the bonding machine.

The invention described in claim 14, therefore, is preferably applied to a method of manufacturing a bonding wire allowing the bonding mounting work in manufacture of semiconductor devices to be effectively performed at a low cost.

Having described specific preferred embodiments of the invention with reference to the accompanying drawings, it will be appreciated that the present invention is not limited to those precise embodiments, and that various changes and modifications can be

effected therein by one of ordinary skill in the art without departing from the scope and spirit of the invention as defined by the appended claims.

CLAIMS

1. A method of manufacturing a bonding wire for a semiconductor device comprising the steps of preparing a wire having a specified diameter; cleaning and annealing said wire; and coating said wire with wire lubricant wherein the adhesiveness of wire lubricant to the wire is increased by the step of cooling said wire directly after final annealing in such a manner that the cooling rate is 1000°C/sec or more.

2. A method in accordance with claim 1 wherein the cooling medium comprises water and said lubricant.

3. A method in accordance with claim 1 wherein the lubricant is applied after cooling.

4. A method in accordance with claims 1,2 or 3 wherein the rate of cooling is controlled by controlling the wire speed (S), temperature in annealing furnace (t_f), cooling medium temperature (t_c) and distance between the outlet of the furnace and the cooling medium surface (l) in the following relationship.

$$\text{Cooling rate} = S \times \frac{(t_t - t_c)}{L}$$

5. A method of manufacturing a bonding wire for a semiconductor device comprising the steps of:

subjecting an ingot of metal prepared by casting to plastic working, and repeatedly to drawing and intermediate annealing, to prepare an intermediate wire;

finally drawing said intermediate wire, to prepare a wire having a specified diameter;

cleaning and finally annealing said wire; and

coating said wire with wire lubricant after cooling,

wherein said method further comprises a means for increasing the adhesiveness of wire lubricant against a wire, said means comprising the step of cooling said wire directly after final annealing in such a manner that the cooling rate defined by the following equation is 1000°C/sec or more,

cooling rate (°C/sec)

= (wire speed) × [(atmospheric temperature in annealing furnace - cooling water temperature)/(distance between outlet of annealing furnace and cooling water surface)].

6. A method of manufacturing a bonding wire for a semiconductor according to claim 5, wherein said cooling rate defined in said equation is 2000°C or more.

7. A method of manufacturing a bonding wire for a semiconductor according to claims 5 or 6, wherein said cooling water is wire lubricant solution.

8. A method of manufacturing a bonding wire for a semiconductor device comprising the steps of preparing a wire having a specified diameter; cleaning and annealing said wire; and coating said wire with wire lubricant wherein said method further comprises a means for increasing the adhesiveness of wire lubricant against a wire, said means including the steps of drawing said wire using water soluble lubricant against a wire, said means including the steps of drawing said wire using water soluble lubricant for cold working prior to the cleaning and annealing; and coating the annealed wire with wire lubricant by dipping said wire in the wire lubricant solution while rewinding said wire and taking out said wire from the solution at an angle between the wire taking out direction and the wire lubricant solution surface, which is specified in the range from 50-60°.

9. A method of manufacturing a bonding wire for a semiconductor device according to claim 8, wherein the cleaning temperature upon cleaning said wire is in the range of 90 to 100°C.

10. A method of manufacturing a bonding wire for a semiconducting device comprising the steps of preparing a wire having a specified diameter; cleaning and annealing said wire; and coating the said wire with wire lubricant, wherein said method further comprises a means for increasing the adhesiveness of the wire lubricant to the wire, said means

including the steps of including the steps of drawing said wire using water soluble lubricant against a wire, said means including the steps of drawing said wire using water soluble lubricant for cold working; and coating the annealed wire with wire lubricant by dipping said wire in the wire lubricant solution while rewinding said wire and taking out said wire from the solution at an angle between the wire taking out direction and the wire lubricant solution surface, which is specified in the range from 50-60^{o}.

11. A method of manufacturing a bonding wire for a semiconducting device comprising the steps of preparing a wire having a specified diameter; cleaning and annealing said wire; and coating the said wire with wire lubricant, wherein said method further comprises a means for increasing the adhesiveness of the wire lubricant to the wire, said means including the steps of applying surface layer removing treatment to said wire before annealing.

12. A method of manufacturing a bonding wire for a semiconducting device comprising the steps of subjecting an ingot of metal prepared by casting to plastic working and repeatedly to drawing and intermediate annealing, to prepare an intermediate wire, finally drawing said intermediate wire, to prepare a wire having a specified diameter; cleaning and finally annealing said wire; and coating the said wire with wire lubricant after cooling, wherein said method further comprises a means for increasing the adhesiveness of the wire lubricant against a wire, said means including the steps of applying surface layer removing treatment to said intermediate wire.

13. A method of manufacturing a bonding wire in accordance with claim 12 wherein said surface layer removing treatment

is performed by etching.

14. A method of manufacturing a bonding wire in accordance with claim 13 wherein said etching is performed using an etching solution containing a surface active agent as an additive.

15. A method of manufacturing a bonding wire in accordance with any one of claims 1-7 wherein said wire is drawn using water soluble lubricant for cold working; and said wire is coated with wire lubricant by dipping said wire in the wire lubricant solution while rewinding said wire and taking out said wire from the solution at an angle between the wire taking out direction and the wire lubricant solution surface, which is specified in the range from 50-60°.

16. A method of manufacturing a bonding wire for a semiconductor device according to claim 15, wherein the cleaning temperature upon cleaning said wire is in the range of 90 to 100°C.

17. A method of manufacturing a bonding wire for a semiconductor device according to claim 1-7 wherein said wire is subjected to a surface layer removing treatment.

18. A method of manufacturing a bonding wire for a semiconductor device according to claim 17 wherein the cleaning temperature upon cleaning said wire is in the range of 90 to 100°C.

19. A method of manufacturing a bonding wire for a semiconductor device in accordance with any one of claims 8-10 wherein said wire is subjected to a surface layer removing treatment.

20. A method of manufacturing a bonding wire for a semiconductor device in accordance any one of claims 1-7 wherein said intermediate wire is subjected to surface layer removing treatment; said wire is drawn using water soluble lubricant for cold working; and said wire is coated with wire lubricant by dipping said wire in wire lubricant solution whil rewinding said wire and taking out said wire from the solution at an angle between the wire taking out direction upon taking out said wire from the solution and the wire lubricant solution surface, which is specified in the range of from 50-60^{o}.

21. A method of manufacturing a bonding wire for a semiconductor device comprising the combination of the method in any of claims 1-7 and the method in any of claims 8-10.

22 A method of manufacturing a bonding wire for a semiconductor device comprising the combination of the method in any of claims 1-7 and the method in any of claims 11-14.

23. A method of manufacturing a bonding wire for a semiconductor device comprising the combination of the method in any of claims 8-10 and the method in any of claims 11-14.

24. A method of manufacturing a bonding wire for a semiconductor device comprising the combination of the method in any of claims 1-7, the method in any of claims 8-10 and the method in any of claims 11-14.

25. A method as herein before described with reference to Figs. 1-4.

The Patent Office

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Claims searched: 1 to 25

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): H1K (KRM) B3A

Int Cl (Ed.6): H01L 21/48 21/60

Other: ONLINE: EDOC WPI JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	EP 0163471 A1 (SUMITOMO)-see page 9 line 28 to page 10 line 12	1-25
A	Patent Abstracts of Japan Section E-1617 vol. 18 no. 545 page 53 & JP6196485	1 to 25
A	Patent Abstracts of Japan Section E-944 vol. 14 no. 292 page 80 & JP2094534	1to 25
A	Patent Abstracts of Japan Section E-868 vol. 14 no. 2 page 85 & JP1251727	1 to 25

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